Inventory and history of the CIRAD cotton (*Gossypium* spp.) germplasm collection

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Summary
Inventory and history of the CIRAD cotton (*Gossypium* spp.) germplasm collection
The CIRAD Cotton Germplasm Collection was founded in 1978 through the pooling of a number of working collections. It is one of the largest collections in the world representing genetic variability in the genus *Gossypium* L. In 2005, it contained 3070 accessions, including 1696 cultivars and 1374 wild and ancestral types, covering five tetraploid species and seven diploid species. The two main cultivated cotton species, G. *hirsutum* L. and G. *barbadense* L., accounted for 68% and 15% of the accessions, respectively. The cultivars originated from around a hundred countries, and the ancestral species accessions were collected during expeditions conducted between 1980 and 1988. Part of the ancestral type collection (894 accessions) was assembled with funding from IBPGR (now Bioversity International), and these accessions were handed over to CIRAD for conservation, assessment and release.

Key words: germplasm collection, cotton, cultivated variety, wild species, historical aspect

Résumé
Inventaire et histoire de la collection de materiel génétique de coton (*Gossypium* spp.) du CIRAD
La collection de matériel génétique de coton du CIRAD a été créée en 1978 en rassemblant un certain nombre de collections. C'est une des plus vastes collections au monde, représentant la variabilité génétique du genre *Gossypium* L. En 2005, elle contenait 3070 accessions, incluant1696 cultivars et 1374 types ancestraux sauvages, englobant cinq espèces tétraploïdes et sept espèces diploïdes. Les deux principales espèces cultivées de coton, G. *hirsutum* L. et G. *barbadense* L., représentent 68 % et 15 % des accessions, respectivement. Les cultivars proviennent d'une centaine de pays et les accessions d'espèces ancestrales ont été collectées au cours d'expéditions effectuées entre 1980 et 1988. Une partie de la collection de types ancestraux (894 accessions) a été réunie avec un financement de l'IBPGR (aujourd'hui Biodiversity International), et ces accessions ont été remises au CIRAD en vue de leur conservation, évaluation et distribution.

Resumen
Inventario e historia de la colección de germoplasma de algodón (*Gossypium* spp.) del CIRAD
La Colección de Germoplasma de Algodón del CIRAD se fundó en 1978 mediante la reunión de una serie de colecciones de trabajo. Es una de las colecciones más grandes del mundo y representa la variabilidad genética del género *Gossypium* L. En el año 2005 contenía 3070 accesiones constituidas por 1696 cultivares y 1374 tipos silvestres y ancestrales, y cubría cinco especies tetraploides y siete especies diploides. Las dos principales especies de algodón cultivado, *G. hirsutum* L. y *G. barbadense* L. representaban el 68 % y el 15 % de las accesiones respectivamente. En las expediciones realizadas entre 1980 y 1988 se recogieron las accesiones de especies ancestrales y los cultivares que tienen origen en unos cien países. Una parte de la colección de tipos ancestrales (894 accesiones) se reunió con ayuda de fondos del IBPGR (ahora Bioversidad Internacional). Estas accesiones fueron enviadas al CIRAD para su conservación, evaluación y libramiento.

Introduction
According to FAO (1996b), a total of 49 000 cotton genotypes are maintained in cotton germplasm collections throughout the world. However, the actual number of different genotypes is certainly much lower due to overlap between these collections. The largest cotton germplasm collections in the world are hosted in USA (8355 accessions; CottonDB 2002); China (6700 accessions; Gao et al. 2000), Russia (6300 accessions; FAO 1996a); India (4500 accessions); France (3070 accessions; pers. comm. CIRAD, Montpellier) and Brazil (2832 accessions; EMBRAPA 2005). There are smaller collections in Pakistan; Argentina (650 accessions, including many wild indigenous *G. barbadense* types, according to Clausen et al. (1996)); Sudan (*G. hirsutum* race *punctatum*), Peru (*G. barbadense* type Tanguis) and Mexico.

Cotton belongs to the family Malvaceae and the genus *Gossypium* L, which consists of 50 species: 45 diploid species with 8 cytotypes (A, B, C, D, E, F, G and K), and 5 tetraploid species with cytotypes A and D belonging to the same genome (Stewart 1995). In *Gossypium*, 4 species are cultivated: 2 of them are diploid of genome A (*G. arboreum* L., *G. herbaceum* L.) and 2 tetraploid of genome AD (*G. hirsutum* L., *G. barbadense* L.). *G. hirsutum* is cropped on 90% of the 36 million hectares of cotton-growing area throughout the world, followed by *G. barbadense* (5%), *G. arboreum* L. and *G. herbaceum* (5%).

The French Cotton Germplasm Collection was set up in Montpellier (France) in 1978. This collection, which has been enriched by accessions collected during many expeditions undertaken over the years, is currently being managed by the French Centre de coopération internationale en recherche agronomique pour le développement (CIRAD). In the present article, we provide details on the origins of the accessions hosted in this collection, including their species, type and geographical distribution. We also describe how our collection is managed and its origin.

Features of the CIRAD collection
The CIRAD Cotton Germplasm Collection currently contains 3070 accessions belonging to 5 tetraploid species and 27

diploid species (Table 1). It includes 1696 obsolete and modern cultivated varieties and 1374 wild or ancestral genotypes collected during expeditions. The wild species are represented by 216 accessions, corresponding to 13 species of genome D, 2 species of genome B, 2 species of genome C, 3 species of genome G, 1 species of genome F (*G. longicalyx*) and 3 wild tetraploid species. The many tetraploid *G. darwinii* accessions (95) and diploid *G. klotzschianum* accessions (45) in the collection were gathered in expeditions carried out in the Galapagos Islands.

The two cultivated tetraploid species represent a major share of the germplasm preserved in the collection: there are 2173 G. *hirsutum* accessions (68.5% of the collection) and 483 G. *barbadense* accessions (15.2% of the collection). Seventy-nine yet unidentified ancestral accessions will have to be classified under one of these two species.

Table 2 shows the distribution of variability within the four cultivated species according to cultivated varieties (cultivars) or landraces (accessions collected in expeditions).

Table 3 shows the geographical origins of the accessions, which originated from around a hundred different countries.

Table 1. Distribution of accessions by cotton species in the CIRAD Cotton Germplasm Collection (2005 inventory).

Species	Genome	Cultivated varieties	Wild or ancestral types	Total
herbaceum	A1	29	21	50
arboreum	A2	27	42	69
anomalum	B1		20	20
capitis viridis	B3		3	3
sturtianum	C1		3	3
robinsonii	C2		1	1
thurberi	D1		6	6
armourianum	D2-1		3	3
harknessii	D2-2		3	3
davidsonii	D3-d		4	4
klotzschianum	D3-k		45	45
aridum	D4		2	2
raimondii	D5		1	1
gossypioides	D6		2	2
lobatum	D7		2	2
trilobum	D8		3	3
laxum	D9		1	1
turneri	D10		1	1
schwendimani	D11		1	1
stocksii	E1		3	3
somalense	E2		3	3
areysianum	E3		1	1
incanum	E4		2	2
bickii	G1		3	3
australe	G		2	2
nelsonii	G		1	1
longicalyx	F1		2	2
hirsutum	AD1	1426	747	2173
barbadense	AD2	214	269	483
tomentosum	AD3		2	2
mustelinum	AD4		1	1
darwinii	AD5		95	95
Not identified			79	79
Total		1696	1374	3070

Table 2. Distribution of accessions of the four cultivated cotton species by species and type in the CIRAD Cotton Germplasm Collection.

Species	Races / types	Total per species	Cultivars	Ancestral forms
G. herbaceum			29	
	africanum			2
	wightianum			1
	Other ancestral forms			18
	Subtotal	50	29	21
G. arboreum			27	
	soudanense			22
	sanguineum			3
	Other ancestral forms			17
	Subtotal	69	27	42
G. hirsutum	American varieties		435	
	African varieties		115	
	Moco type (Brazil)		29	
	Other cultivars		847	
	latifolium			9
	marie-galante			523
	morillii			5
	palmeri			13
	punctatum			62
	richmondii			7
	yucatanense			77
	Other ancestral forms			51
	Subtotal	2173	1426	747
G. barbadense	Sea Island type		41	
	Egyptian type		55	
	Tanguis type		34	
	Mono type		35	
	Pima type		16	
	Aspero type		16	
	Other cultivars		17	
	brasiliense			31
	Other ancestral forms			238
	Subtotal	483	214	269
Total		2775	1696	1079

Management of genetic resources in the collection

Germplasm conservation conditions

Each accession is maintained in a cold room at 4°C and 40% relative humidity. They are kept in the form of samples of carefully sorted self-pollinated seeds (275 g samples for cultivars and 75 g samples for genotypes collected in expeditions). The oldest seeds in the collection are rejuvenated annually and, since 1999, rejuvenated seed samples (25 g per accession) are stored in a freezer (-18°C). In this way a duplicate of the collection is gradually being assembled. The samples (25 g or 150 g) are placed in individual boxes (Photographs 1 and 2), and sealed with Parafilm®. Prior to being placed in these storage boxes, the seeds are dried in a ventilated oven for 48 h at 35°C to reduce their intrinsic moisture level to 5%. The germination rate is checked and cannot be less than 80% when an accession is first placed in storage in the collection. Under these conditions, the seeds maintain a high germination rate for more than 20 years in cold storage. Freezer storage of seeds has not been carried out for long enough to be able to determine the potential cottonseed storage life under these conditions.

Table 3. Geographical distribution of accessions of the CIRAD Cotton Germplasm Collection.

Countries	Total	Cultivars	Wild types	Countries	Total	Cultivars	Wild types
Algeria	4	3	1	Malawi	7	7	0
Antigua	44	16	28	Maldives	7	0	7
Argentina	25	23	2	Mali	21	16	5
Australia	26	22	4	Mauritania	3	0	3
Bahamas	1	0	1	Mauritius	1	0	1
Bangladesh	65	65	0	Mexico	112	2	110
Barbados	25	15	10	Montserrat	6	6	0
Belize	1	1	0	Morocco	10	9	1
Benin	10	8	2	Myanmar	2	2	0
Bolivia	15	7	8	Namibia	1	0	1
Botswana	1	0	1	Nicaragua	24	18	6
Brazil	58	54	4	Nigeria	16	11	5
Bulgaria	26	25	1	Oman	4	0	4
Burkina Faso	12	12	0	Pakistan	14	14	0
Burundi	24	23	1	Panama	1	0	1
Cayman Islands	8	0	8	Paraguay	28	22	6
Cameroon	123	32	91	Peru	110	55	55
Cape Verde	4	0	4	Philippines	17	2	15
Central African Republic	15	13	2	Puerto Rico	23	0	23
Chad	89	86	3	Romania	1	1	0
Chile	2	0	2	Russia	1	1	0
Continental China	73	71	2	St Kitts and Nevis	6	0	6
Colombia	90	0	90	St Vincent	2	0	2
Costa Rica	27	11	16	St Lucia	10	0	10
Côte d'Ivoire	122	122	0	Senegal	15	2	13
Czech Republic	2	0	2	Seychelles	1	0	1
Dem. Rep. of the Congo	29	6	23	Somalia	1	1	0
Dominica	10	0	10	South Africa	18	14	4
Dominican Republic	35	0	35	Spain	18	18	0
Ecuador	146	4	142	Sudan	24	3	21
Egypt	25	25	0	Syria	10	10	0
El Salvador	21	20	1	Tanzania	13	13	0
France†	299	4	295	Thailand	24	23	1
Gambia	1	0	1	Togo	60	52	8
Greece	31	31	0	Trinidad and Tobago	61	0	61
Guatemala	7	0	7	Turkey	10	10	0
Guinea-Bissau	1	0	1	Uganda	36	36	0
Haiti	33	0	33	USA	448	435	13
Hawaii	2	0	2	Uzbekistan	52	51	1
India	24	21	3	Vanuatu	1	0	1
Indonesia	3	3	0	Venezuela	92	0	92
Iran	36	33	3	Viet Nam	20	17	3
Israel	18	18	0	Yemen	2	0	2
Jamaica	32	3	29	Zambia	28	17	11
Lao PDR	15	9	6	Zimbabwe	17	17	0
Madagascar	2	1	1	Unknown	22	16	6
Macedonia	8	8	0	Total	3070	1696	1374

Note: † France includes overseas departments and territories (Guadeloupe, Martinique, Réunion, New Caledonia and French Guiana).

Figure 1. Cold room for storage of the seed collection. Photograph: Dominique Dessauw

Figure 2. Seed storage boxes. Photograph: Dominique Dessauw

Each accession is rejuvenated every 12–15 years by sowing and selfing the seeds. The seeds were multiplied in Guadeloupe from 1979 to 1988, in Costa Rica from 1989 to 1994 and from 1998 to 2002, in Chad in 1996 and 1997, and in Cameroon from 2003 up to now.

Access conditions

The cultivars are managed according to regulations of the International Union for the Protection of New Varieties of Plants (UPOV). Free access is granted to obsolete varieties that have become public domain (New Plant Variety Certificate more than 20 years old) after a Material Transfer Agreement is signed. A research agreement is drawn up for protected varieties obtained by CIRAD in collaboration with its partners. No access is authorized for other protected varieties maintained in the Cotton Germplasm Collection, but CIRAD can use this material for its own research purposes. The CIRAD collection regularly fulfils seed requests from research institutions in many countries (Brazil, Cameroon, Israel, Pakistan, Paraguay, Thailand, etc.) to increase the variability available for breeding.

All wild types were collected prior to 1992, when states were granted sovereign rights over genetic resources within their borders (Rio Earth Summit). Since then, there have been no further introductions of ancestral and wild material into the CIRAD collection. The Convention on Biological Diversity (CBD) was endorsed at the Rio Earth Summit and became effective on 29 December 1993. It recognizes the global distribution of *ex situ* conserved phytogenetic resources and the sovereign right of states over their genetic resources conserved since, but not prior to, this date.

CIRAD is a custodian of plant material collected with funding from IBPGR (now Bioversity International). This material is registered in Bioversity's reference germplasm collections, with free access granted to any interested professional or institutional stakeholder. This unique material is freely available worldwide.

History of expeditions conducted worldwide and of the CIRAD collection

The history of cotton germplasm collections began in 1784, with a botanical garden at Sainte Croix in the Virgin Islands (Rohr 1791–1793). In 1860, there was a second significant attempt to assemble a collection, in Italy, at the royal botanical garden in Palermo (Todaro 1877). At the beginning of the 20th century, several collections were established in Trinidad (collection created in 1926 and dispersed in 1947), Sudan, Argentina, ex-USSR, India, Czechoslovakia and USA (Fryxell 1984). These collections were used by botanists and cytogeneticists to determine the relationships between the different species (Hutchinson *et al.* 1947; Valicek 1979).

In addition to these collections, private companies and public institutions have developed working collections that are used by their breeders to create new varieties. In the 19th century, cotton improvement programmes were initiated in USA (mainly on G. *hirsutum*), Egypt (G. *barbadense*) and India (G. *arboreum* and G. *herbaceum*). In the 20th century, the number of cotton-growing countries increased quickly with the expansion of colonial empires (Africa, Australia), the development of new cropping areas (Brazil, Central Asia, China, Indus Valley, Turkey) and the increase in industrial needs associated with the high world population growth. There was a concomitant increase in cotton improvement programmes to meet the rising agricultural demand for cultivars adapted to a broad range of climatic conditions.

During the 20th century, accessions were collected in Mexico, Guatemala, Ecuador, Salvador and Colombia in different botanical expeditions undertaken between 1902 and 1956 (Percival *et al.*, 1999). In 1960, a survey was carried out in Argentina, Bolivia and Paraguay to find and collect ancestral forms of G. *barbadense* (Gutierrez et al. 1960).

As of the 1960s, the focus was systematically placed on safeguarding genetic resources of the main crop species. Under the aegis of FAO, IBPGR thus decided to promote botanical collections and expeditions, and cotton benefited from this new policy. Between 1976 and 1990, the centres

of origin and domestication of *Gossypium* species were surveyed (Australia, Colombia, Ecuador, French Guiana, Guatemala, Mexico, Peru, Venezuela and West Indies). CIRAD participated in these expeditions. Very few new expeditions were conducted thereafter, apart from a survey conducted in Cameroon in 1988 by Seignobos and Schwendiman (1991), in Australia in 1993 (Stewart, 1995) and another in India between 1999 and 2002 by the Central Institute for Cotton Research (CICR) (Singh et al. 2003).

The French collection was founded in 1978 with 560 accessions that came from cultivar collections assembled by research teams of the Institut de Recherche du Coton et des Textiles exotiques (IRCT)—integrated into CIRAD in 1992—that were conducting research worldwide (Burkina Faso, Cameroon, Central African Republic, Chad, Côte d'Ivoire, Mali, Paraguay, Senegal, Togo). As of 1980, IRCT, in partnership with IBPGR, undertook expeditions to collect ancestral tetraploid and diploid forms belonging to genome D in *G. hirsutum* and *G. barbadense* centres of origin and dispersal. During these expeditions, collected seeds were divided into three batches (with one remaining in the surveyed country, one sent to the National Center for Genetic Resources Preservation (NCGRP) in Fort Collins (USA) and one kept by IRCT). Only two samples were formed when the quantity of seeds collected

Table 4. List of Bioversity International (formerly IBPGR/IPGRI) expeditions conducted from 1980 to 1985.

Code	Collectors	Countries	Dates	Number of accessions		
				Collected	Introduced into CIRAD collection	Conserved in 2005
CN 031	Perret P. Sheuring J.	Mali	December 1981 to February 1982	4	4	3
CN 111	Croston R.P.	Sudan	November 1981	3	3	3
CN 140	Ano G. Schwendiman J.	West Indies	January to March 1980	227	215	204
CN 141	Ano G. Schwendiman J.	French Guiana Venezuela Colombia	January to February 1981	264	243	238
CN 196	Ano G. Schwendiman J.	Peru	October to November 1981	53	48	43
CN 197	Ano G. Percival A.E. Schwendiman J.	Mexico St Kitts	February to March 1982	80	78	75
CN 204	Ayad W.G. Croston R.P.	Republic of Yemen	May to June 1980	1	1	1
CN 209	Mehra K.L.	Zambia	April to June 1981	8	8	8
CN 212	Attere A.F.Y. Ndumba E.K. Mubiana W	Zambia	June to July 1982	3	3	3
CN 237	Ano G. Percival A.E. Schwendiman J.	Ecuador Galapagos	September to December 1983	264	212	141
CN 285	Ano G. Percival A.E. Schwendiman J.	West Indies	February to March 1985	307	170	161
CN 349	Thomann R. Contreras A. Rick C.M. Holle M. Grana J.	Chile	April 1986 to March 1988	2	2	2
CN 401	Mehra K.L.	Maldives	October to December 1986	9	9	7
CN 433	Guarino L.	Sultanate of Oman	April to July 1987	4	4	4
CN 441	Mokkadem A. Chadja H. Guarino L.	Algeria	May to July 1988	1	1	1
Total				1230	1001	894

was insufficient—one for the surveyed country and the other destined for the gene libraries at Fort Collins or IRCT.

Six expeditions (Table 4) were thus undertaken between 1980 and 1985, in Guatemala, Mexico and the West Indies (centre of origin of G. *hirsutum*), Colombia, Ecuador and Peru (centre of origin of G. *barbadense*), Venezuela and French Guiana, and in the Galapagos Islands (centre of origin of G. *darwinii* and G. *klotzschianum*). 1230 accessions were collected in these expeditions. The CIRAD Cotton Germplasm Collection still contains 894 accessions derived from these expeditions. The collection has been further enriched with seeds collected in other expeditions (African countries and the Arabian Peninsula) or obtained through exchanges with different countries, or collections donated by partners, especially the Royal Botanic Gardens, Kew (UK), and the Université des sciences agronomiques de Gembloux (Belgium). In 1987 and 1988, 86 genotypes (G. *herbaceum*, G. *arboreum*, G. *barbadense* and G. *hirsutum*) were collected during two expeditions carried out to obtain varieties traditionally cropped in mountainous areas of northern Cameroon.

Conclusion

The French Cotton Germplasm Collection, which was founded in Montpellier (France) in 1978, conserves 3070 accessions belonging to 5 tetraploid species and 27 diploid species. This collection has been enriched with material collected in many expeditions conducted over the years, some of which were funded by Bioversity International (formerly IBPGR/IPGRI). This collection is currently hosted by the French Centre de coopération internationale en recherche agronomique pour le développement (CIRAD). This essential collection releases interesting cotton accessions useful for breeding programmes involving traditional selection, cytogenetics or marker-assisted selection strategies.

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